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Babaev

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(54) **ULTRASOUND SURGICAL SAW**

(76) Inventor: **Eliaz Babaev**, Minnetonka, MN (US)

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A61B 17/14 (2006.01)

(52) **U.S. Cl.**
CPC ***A61B 17/320068*** (2013.01); ***A61B 17/14*** (2013.01); ***A61B 17/148*** (2013.01); *A61B 17/141* (2013.01); *A61B 2017/320076* (2013.01)

(58) **Field of Classification Search**
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USPC 606/45, 79, 82, 84, 85, 169–171, 177; 83/835, 846, 847, 854, 855
See application file for complete search history.

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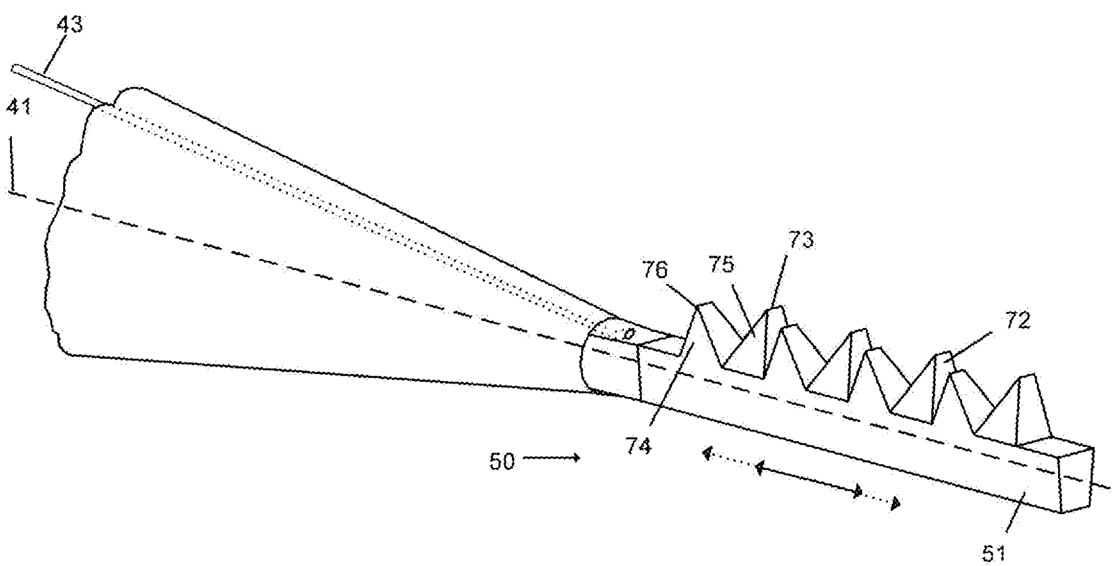
Primary Examiner — Sarah W Aleman

(57) **ABSTRACT**

This invention discloses methods and devices using ultrasound energy for resecting bone tissue during surgical procedures. The disclosure describes the use of ultrasound surgical saw consisting of an ultrasound generator, ultrasound transducer and ultrasound horn including a cutting blade to resect bone tissue without excessive temperature rise during typical surgical procedures. The cutting blade provides a self-clearing design that includes at least two teeth disposed to prevent accumulation of bone chips within the proximity of the teeth. The design of the cutting blade allows the mechanical motion of the blade and the emission of the ultrasound energy to remove accumulated bone chips and prevent excessive temperature rise.

13 Claims, 8 Drawing Sheets



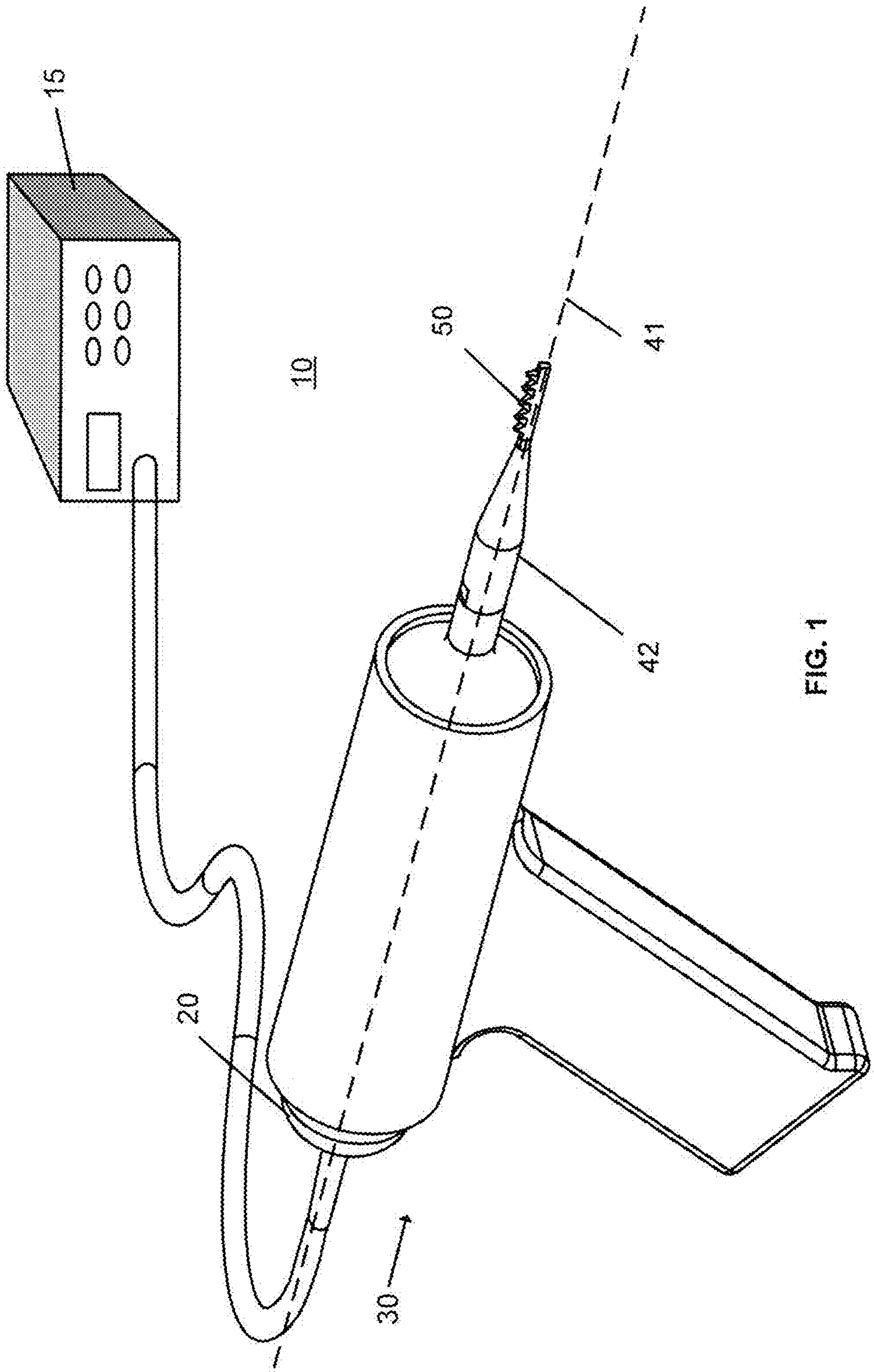


FIG. 1

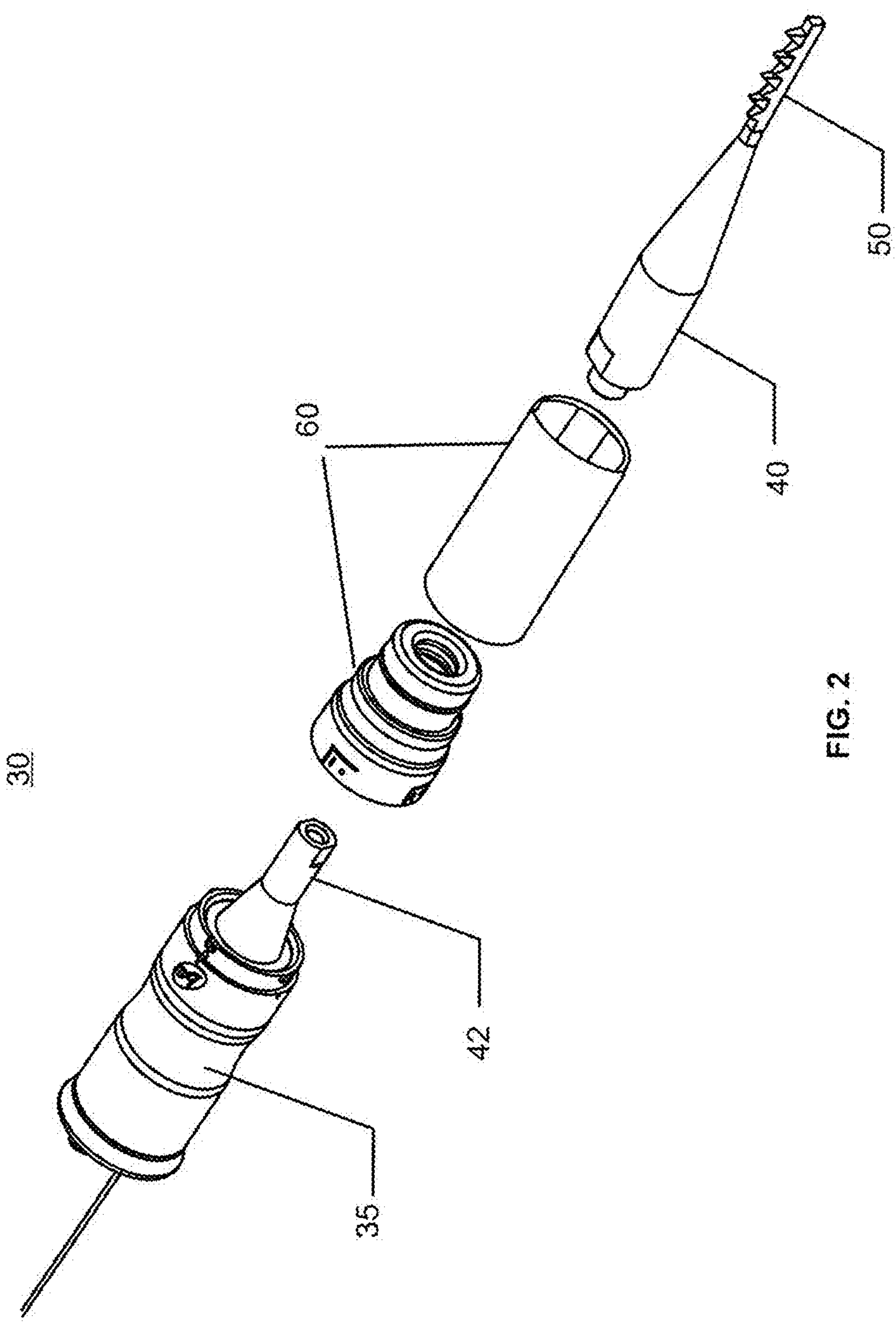


FIG. 2

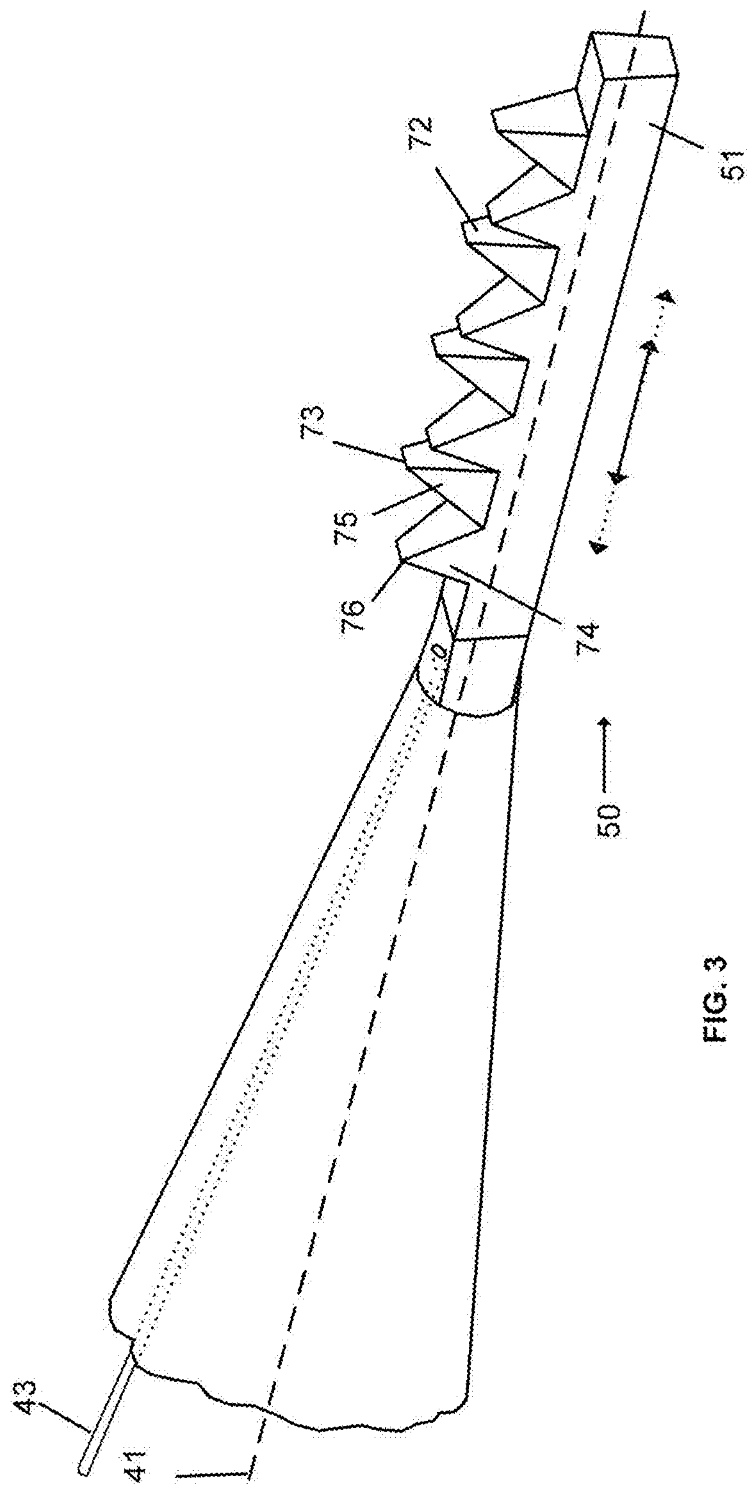


FIG. 3

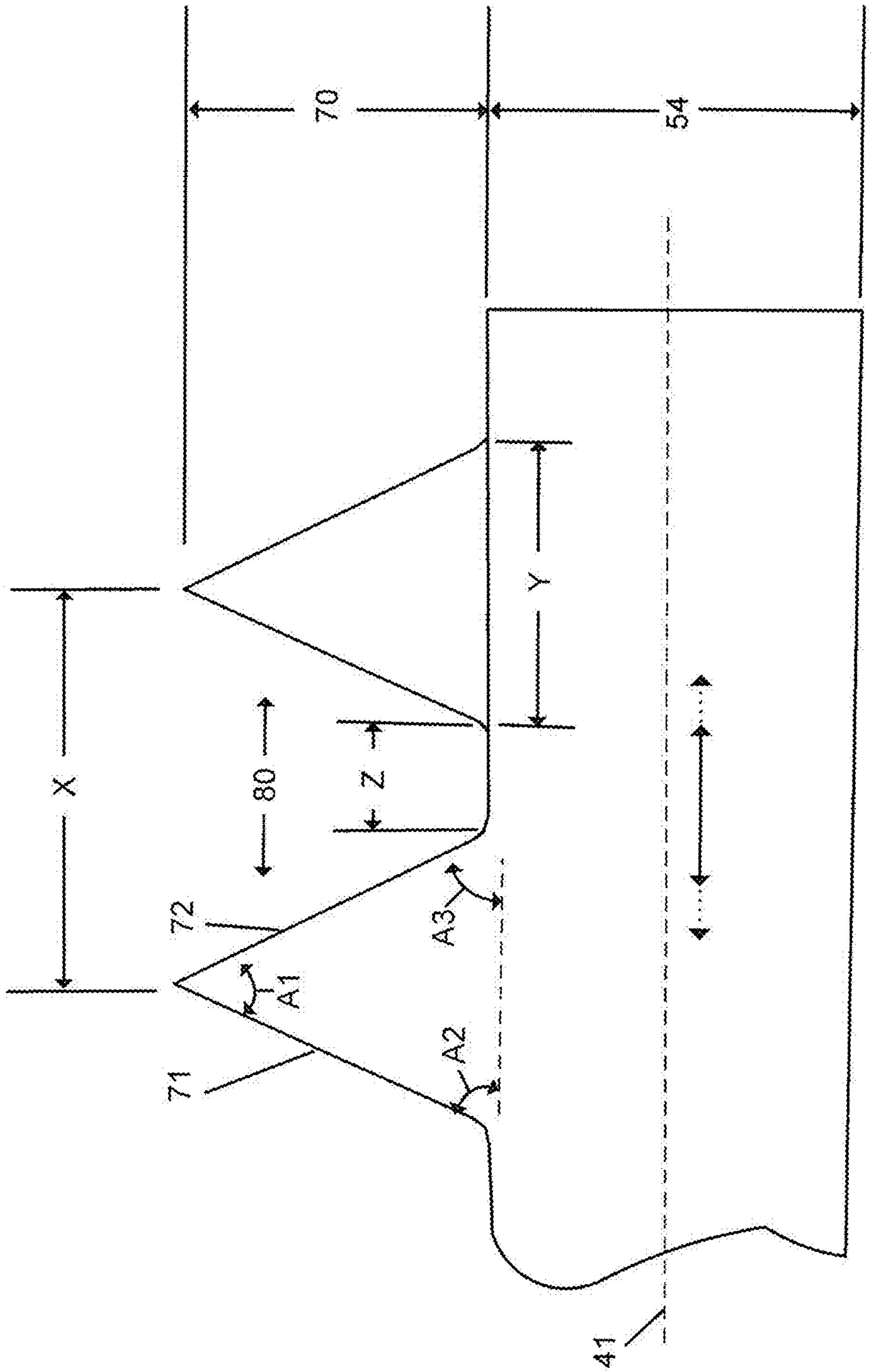


FIG. 4

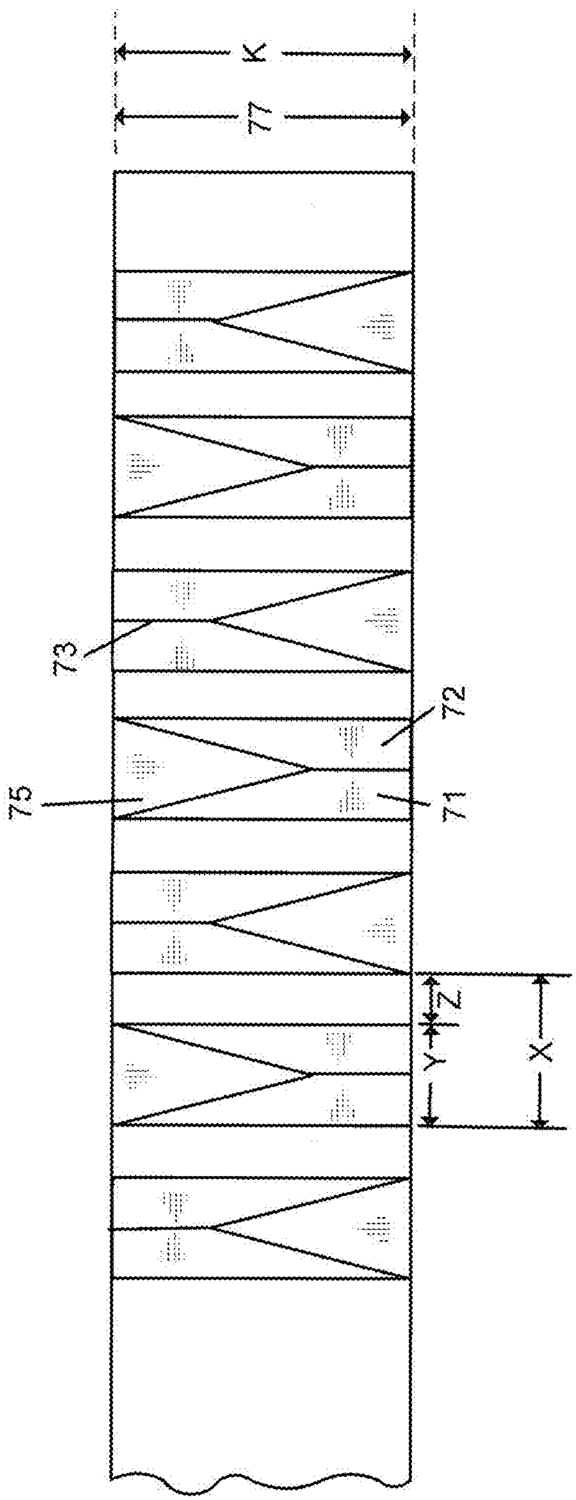


FIG. 5

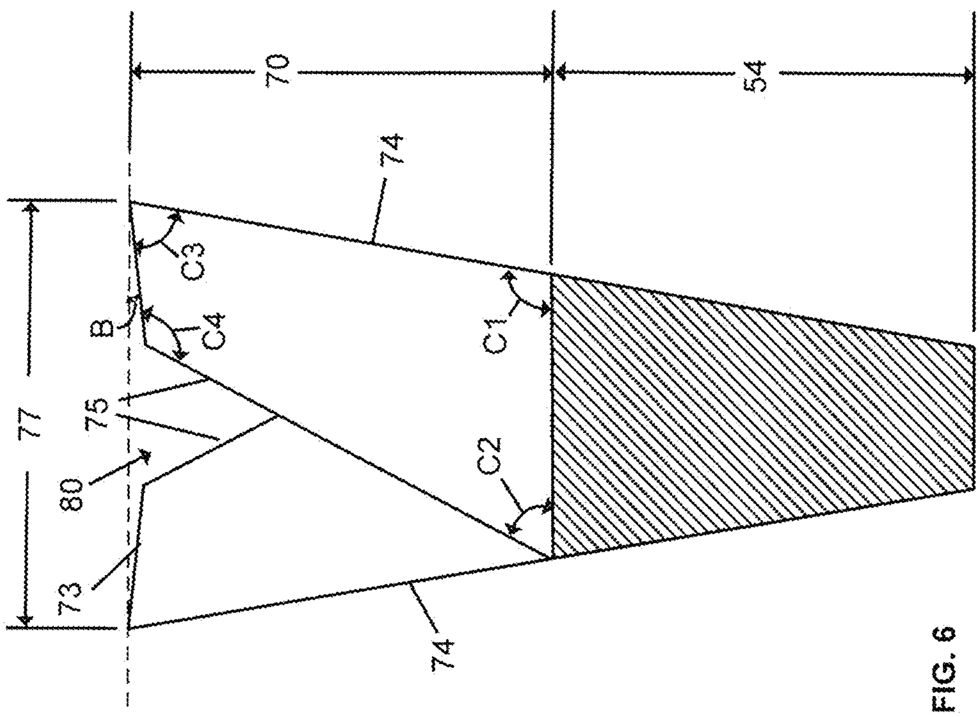


FIG. 6

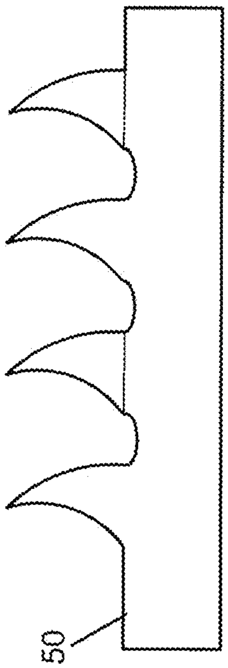


FIG. 9

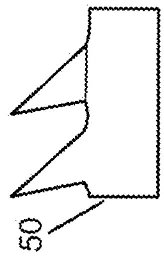


FIG. 10

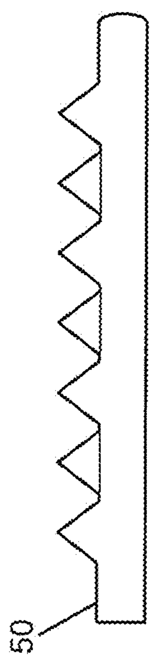


FIG. 7

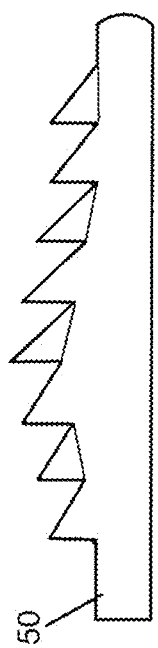


FIG. 8

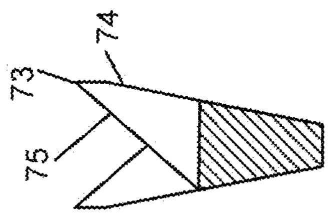


FIG. 13

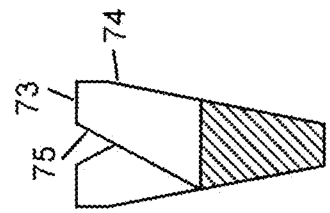


FIG. 15

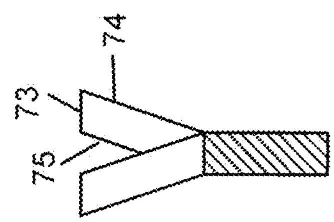


FIG. 12

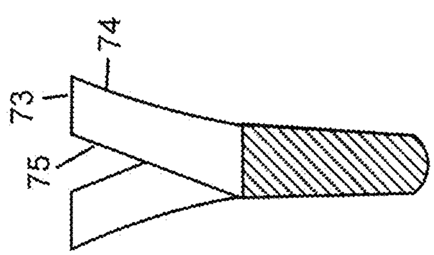


FIG. 14

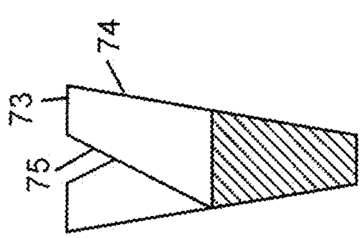


FIG. 11

ULTRASOUND SURGICAL SAW

BACKGROUND OF THE INVENTION

The following invention relates generally to instrumentalities for cutting bone during surgery. More particularly, the instant invention is directed to a high speed surgical saw which uses a drive mechanism to move a cutting blade back and forth at a high frequency. The drive mechanism is needed to impart a back and forth motion to the cutting blade and may be, for example, a reciprocating, semi-oscillating or ultrasound drive. In the preferred embodiment, described in detail herein, a ultrasound transducer is utilized as part of the drive mechanism for the surgical saw blade with a self-cleaning design. The surgical saw blade may have a distal portion having at least one pair of teeth configured to be adjacent to each other and each of the pair of teeth having a cutting edge which is oriented with the teeth so that the cutting edge is disposed away from a centrally positioned longitudinal axis between the teeth. A gullet is then formed between the teeth, creating a cavity along the longitudinal axis of the ultrasound horn.

Typical procedures requiring bone removal or resection include surgeries to repair injuries such as orthopedic surgeries or back surgeries, as well as surgeries to access other tissues such as temporary skull resection to access the brain or vertebrae removal to access a spinal cord.

One of the most vexing problems that surgeons face when using ultrasound surgical saws when cutting bone tissue is the rapid temperature rise of the saw blade due to the accumulation of bone chips within the area of the saw teeth. Since tissue necrosis quickly occurs at temperatures greater than 75° C. (degrees centigrade), a rapid temperature rise of an ultrasound surgical saw is a significant problem which may injure or destroy the bone tissue itself as well as other adjacent tissues. The problem is particularly significant since while working the surgeon can neither see nor feel whether he has caused damage, which only becomes subsequently apparent.

When such necrosis occurs, the tissue does not grow into the cut site, fracture site, or surface of the cement-less prosthesis or other prosthesis and may fail to knit. In the absence of knitting, the prosthesis may not be anchored by bone growth, possibly resulting in the necessity to have a replacement operation some period of years thereafter. In some instances, half of all knee or hip operations may be revision procedures, often because in the initial operation, where temperature is a contributing factor, excessive temperatures were reached at the site of the shaped surface or bone kerf (or cut).

An accumulated bone chip grit trapped within the teeth of a saw blade tends to get vibrated at ultrasonic frequencies. This is known to cause the temperature of a saw blade and surrounding tissue to increase very quickly. This effect may limit the use of a device to a maximum period of less than 1-minute before a surgeon must stop cutting to avoid tissue necrosis due to overheating.

SUMMARY OF THE INVENTION

As would be readily apparent to a person of ordinary skill in the art, the disclosed invention would be particularly beneficial to be used for surgeries requiring precision cutting, removing or shaping bone tissue. The invention is directed to a high speed surgical saw which uses a drive mechanism to move a cutting blade back and forth at a high frequency. The drive mechanism used to impart a back and forth motion to the cutting blade may be a purely mechanical device such as a rotary, reciprocating or semi-oscillating drive generally operating at speeds in excess of 20,000 strokes per minute. A cutting blade may be directly or indirectly attached to the drive mechanism as described herein. In the preferred embodiment, described in detail herein, a ultrasound transducer is utilized as part of the drive mechanism for the surgical saw blade with a self-cleaning design. Furthermore, the disclosed methods and devices may also be useful in other applications such as veterinary and autopsy purposes.

For descriptive purposes, the present invention is generally shown as in its ultrasound embodiment. The apparatus comprises an ultrasound generator driving an ultrasound transducer. An ultrasound horn is mechanically coupled to the ultrasound transducer. The ultrasound horn consists of an ultrasound tip or cutting blade and may also include a shaft. The ultrasound horn may also include one or more conduits to provide and/or remove fluids and other materials from the surgical site. The ultrasound horn receives the ultrasound waves from the ultrasound generator and transmits the ultrasound waves to the proximal end of the cutting blade either directly or through the shaft. The shaft and the cutting blade may be integral parts of the ultrasound horn or may be mechanically coupled as one unit.

A housing substantially encompassing the ultrasound transducer and provides a hand piece for convenient holding and manipulating the device. The housing covers the ultrasound transducer and at least portions of the ultrasound horn.

The hand piece may be provided in a variety of configurations. For example, the hand piece may be of a substantially cylindrical shape serving as a grip portion around the longitudinal axis of the ultrasound transducer, or it may be positioned to extend radially from the longitudinal axis of the ultrasound transducer serving as a grip portion having a pistol grip design.

An ultrasound saw will operate at very high rates of speed and with a very short stroke length. The stroke speed is controlled by the ultrasound transducer frequency which may be for example 30,000 strokes per second. The stroke length is controlled by the longitudinal displacement of the ultrasound horn at a particular point, and may be, for example, 80 microns. The high frequency and short stroke length combine to make bone chip ejection a difficult issue to resolve. The accumulation of bone chips then result in friction between the cutting blade and the tissue which generates additional heat. The present invention addresses the problem of rapid heat generation at the cutting blade due to lack of efficient chip removal which is recognized as one cause of excessive heat generation. In surgical situations, such unwanted heat generation is undesirable because of thermal necrosis which damages bone structure adjacent to the cut. Having a cutting edge on a tooth that does not extend across the entire width of the kerf greatly enhances the ability of the cutting blade to clear unwanted bone chips.

In addition to longitudinal movement, the ultrasound horn generates radial energy at points along the ultrasound horn. By controlling teeth geometry, this energy can be focused to assist bone chip removal by directing energy radially from the cutting blade to help move the bone chip material away from the cutting blade.

Furthermore, the present invention allows design of a very thin cutting blade. In addition to allowing for the precision cuts that are desirable for surgical procedures, the thin cutting blade also allows for greater heat dissipation which prevents heat buildup in the blade.

In addition, the plugging of the teeth also results in loss of cutting ability of the saw. Chips of bone that accumulate within the saw kerf and around the saw teeth, prevent the cutting edges of the teeth from contacting, the tissue to be cut.

This decreases the aggressiveness of the cutting action and may transform the cutting action to an abrading action rather than chipping. This may require the surgeon to apply more hand force to achieve any progress with the cut and may result in additional heat generation as well as increased surgeon fatigue.

Another problem noted in existing blades involves the tendency of the saw to initially wander rather than to form a kerf. This may be a desirable feature in a device used for shaping bone, but is problematic when a surgeon desires a precise cut at a precise location. In the invention, a temporary a center bone ridge located in the gullet between adjacent teeth is used to help guide and stabilize the cutting blade

The gullets between adjacent teeth are open to each other to form a continuous cavity along the longitudinal axis of the cutting blade. In its essence, the blade of the invention takes into consideration the natural tendencies at play when a surgeon is cutting a bone with an ultrasound surgical saw. In general, the cutting action is parallel to the longitudinal axis of the ultrasound horn. The geometric design of the teeth, in cooperation with the ultrasound energy being emitted from the surfaces and edges of the teeth, cooperate to eject bone chips laterally from the cutting edges using the radial energy from the ultrasound horn.

Typically very thin cuts are desired during bone surgery. By minimizing the kerf, faster healing is promoted since a patient's body needs to generate less tissue to heal. One attribute of the instant invention is that each working tooth cooperatively cuts some material with its adjacent working tooth so that collectively, the teeth make progressive contributions to generate a kerf that may achieve a desired width of approximately 1 mm.

Accordingly, it is the primary object of the present invention to provide a novel and useful ultrasound saw for use in open surgery as well as minimally invasive, cannula based surgical techniques.

A further object of the invention is to provide a device that may be utilized by direct manual manipulation by a surgeon, as well as conventional robotic or remote control procedures.

A further object of the present invention is to provide a device as characterized above which minimizes the degree of heat buildup associated with the surgical cutting to reduce the thermal necrosis that attends cutting bone.

A further object of the present invention is to provide a device as characterized that reduces buildup of bone chips within the saw kerf and between the saw teeth using a self-clearing design to clean out the saw kerf.

A further object of the present invention is to provide a device as characterized above which can be relatively economically manufactured, lends itself to mass production techniques and is extremely durable in construction.

A further object of the present invention is to provide a device as characterized above which cuts aggressively and has a tendency to initially form a kerf, and self centers itself and cuts through the bone quickly within which the blade will reside.

A further object of the present invention is to provide a surgical saw blade having a centrally positioned longitudinal axis, a proximal end (proximal meaning closest to surgeons handpiece or normal gripping position) configured to couple to an ultrasound horn and a distal end (farthest from surgeons handpiece) having at least one pair of teeth having tips for cutting bone which are configured to be adjacent to each other and wherein each tooth have a cutting edge less than the width of the kerf, the pair cooperating to form the kerf.

Another aspect of the invention is to provide a device with teeth positioned along the radial surface of an ultrasound horn, substantially parallel to the ultrasound horn's longitudinal axis.

Another aspect of the invention is to provide a device with an ultrasound transducer and an ultrasound horn positioned along a similar longitudinal axis. Another aspect of the invention is to provide a device with an ultrasound horn having a conduit for providing or removing a fluid to the surgical site.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts a perspective view of one embodiment of the ultrasound apparatus.

FIG. **2** depicts a perspective view of one embodiment of the ultrasound apparatus.

FIG. **3** depicts a perspective view of one embodiment of the cutting blade.

FIG. **4** depicts a side view of an alternative embodiment of the cutting blade.

FIG. **5** depicts a top plan view of an embodiment of the cutting blade.

FIG. **6** depicts a cross sectional view of an alternative embodiment of the cutting blade.

FIG. **7** depicts a side view of an alternative embodiment of the cutting blade.

FIG. **8** depicts a side view of an alternative embodiment of the cutting blade.

FIG. **9** depicts a side view of an alternative embodiment of the cutting blade.

FIG. **10** depicts a side view of an alternative embodiment of the cutting blade.

FIG. **11** depicts a cross sectional view of an alternative embodiment of the cutting blade.

FIG. **12** depicts a cross sectional view of an alternative embodiment of the cutting blade.

FIG. **13** depicts a cross sectional view of an alternative embodiment of the cutting blade.

FIG. **14** depicts a cross sectional view of an alternative embodiment of the cutting blade.

FIG. **15** depicts a cross sectional view of an alternative embodiment of the cutting blade.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is an ultrasound medical method and device for use during surgical procedures. Several embodiments and details of the invention are shown in FIGS. **1-15** and described herein. The disclosure describes the apparatus and methods in reference to surgical procedures on bones, however the invention is appropriate for other surgical procedures generally.

FIG. **1** depicts one possible embodiment of the ultrasound apparatus **10** of the present invention. The depicted embodiment comprises an ultrasound generator **15** with an electrical cord supplying the ultrasound generator **15** its power, such as standard AC or battery power. The ultrasound generator **15** is in electrical communication with an ultrasound transducer **20** through a signal connector. A power switch may be provided to activate the ultrasound apparatus **10**. The switch, for example, may be foot activated or a trigger or button located on the handpiece or generator.

As shown by example in FIGS. **1** and **2**, the handpiece **30** may be in various embodiments. A surgeon manipulates hand piece **30** containing an ultrasound transducer **20**, a housing **35**, an ultrasound horn **40** and optionally a shield **60**. The ultrasound transducer **20** is driven by the ultrasound generator

15. The housing **35** surrounds the ultrasound transducer **20** and provides a gripping surface. The housing **35** may cover portions of the ultrasound horn **40**. The ultrasound horn **40** is connected to the distal end of the ultrasound transducer **20** along a longitudinal axis **41**. Placing the ultrasound horn **40** and the ultrasound transducer **20** along a longitudinal axis **41**, increases the efficiency of the ultrasound transmission through the ultrasound horn **40** and reduces the chances of metal cracking or breaking within portions of the ultrasound horn **40** such as at the cutting blade **50** at the ultrasound tip. This can be a severe problem due to the high operating frequency and thin width of the cutting blade **50** that are preferred. The ultrasound horn **40** includes at least a cutting blade **50** and may include a shaft **42** disposed between the cutting blade **50** and the ultrasound transducer **20**. The ultrasound horn **40** may optionally include one or more conduits **43** as shown in FIG. **3** for adding a fluid to the surgical site or removing (aspirating) fluid from the surgical site. Openings between and among the teeth may allow movement of fluid along the length of the cutting blade. Additional conduits and/or channels may be provided on the cutting blade **50** to further distribute the fluid. The use of a channel for aspirating fluids would include removing blood, other body fluids or added fluids that generally accumulate at a surgical site. Examples of possible uses for the addition of fluids include supplement cooling, lubrication or therapeutic purposes.

A shield **60** optionally attached to the housing **35** covers at least portions of the ultrasound horn **40** to prevent undesirable contact between the ultrasound horn **40** with the patient's tissue and/or surgeon's hand. The shield **60** may extend the entire length of the cutting blade **50** with an opening exposing the teeth **70** of the cutting blade **50**. The shield **60** may be rigid or flexible material such as aluminum or various plastic materials as well as of a disposable or sterilizable design.

The ultrasound generator **15** and ultrasound transducer **20** are well known in the art and will not be described in detail herein. However, control of the electrical signal directly influences the ultrasound wave properties and allows optimization of the ultrasound treatment particularly with respect to the ultrasound thermal, cavitation and microstreaming properties. The ultrasound generator **15** should be capable of producing an electrical signal of a sufficient alternating voltage to drive the ultrasound transducer **20** and to achieve the desired therapeutic effect. The ultrasound transducer **20** converts the alternating voltage into mechanical motion as to induce a shaft **42** to vibrate. The shaft **42** transmits the ultrasonic vibrations to the ultrasound tip with cutting blade **50** to induce vibrations. The amplitude of the vibrations is typically between approximately 1 micron and approximately 300 microns. The preferred amplitude range is approximately 60 microns-100 microns. The recommended amplitude value is approximately 80 microns.

The magnitude of the longitudinal ultrasonic vibrations provides the mechanical energy to move the cutting blade **50** back and forth along the longitudinal axis **41**. The geometric conformation of the teeth and the position of the teeth relative to each other assist with the self-clearing properties of the cutting blade **50**.

During use of the handpiece **30** the electrical signal produced by ultrasound generator **15** should also be sufficient to drive the ultrasound transducer **20** to induce the cutting blade **50** stroke frequency to vibrate approximately in resonance at any frequency within the ultrasound spectrum, such as, but not limited to, between approximately 15 kHz and approximately 3 mHz. The preferred frequency range for the cutting blade **50** is 15 kHz to 50 kHz with a recommenced frequency of approximately 30 kHz. The ultrasound generator **15** may have multi-frequency capabilities to operate at selectable alternative frequencies within the ranged utilized.

The ultrasound transducer **20** may be driven with a continuous wave or pulsed frequency signal supplied by ultrasound generator **15**. Driving transducer **20** with a continuous wave tends to induce the release of standing waves from the various surfaces of the cutting blade **50**, while a pulsed frequency reduces or avoids the release of standing waves. The pulsed frequency signal generates less heat, cavitation and streaming currents, and may increase the longitudinal force of the induced vibrations as a result of the on/off cycle changes. The electrical signal may be changed depending on the desired features of the released ultrasound waves for the particular application. For example, inducing the release of standing waves from the cutting blade **50** may be helpful to produce or increase cavitation effects and thereby self-cleaning properties. The wave form of the electrical signal may be sinusoidal, rectangular, trapezoidal and/or triangular. In addition, the electrical signal from the ultrasound generator **15** may be fixed or modulated to allow ultrasonic wave amplitude variability. The ultrasound generator **15** may include feedback control to adjust the signal.

To conduct bone surgery requires access to the patient's tissue beneath the surface of the skin. This can be accomplished through open surgery by an incision through the skin, muscle and other tissues to access the bone. The access may be completed with this or other tools. It may also by accomplished by minimally invasive techniques were the patient's tissue is accessed through skin punctures and the surgery is conducted through cannula based narrow diameter instruments, with cameras and/or other sensors being used for visualization.

A housing **35** serving as a handle for the ultrasound device isolates the vibrations of ultrasound transducer **20** from being transferred to the surgeon holding the device. Operators of the ultrasound device can hold the housing **35** during use to manipulate the device. The housing **35** provides a surface appropriate for hand manipulation by the surgeon and/or user while allowing the user to avoid direct contact with vibrations within the device. The housing may extend over the entire ultrasound transducer **20** and/or may partially enclose portions of the shaft **42**. FIG. **1** shows a grip portion in an axial configuration. FIG. **2** shows the housing **35** incorporating a grip portion similar to a pistol grip configuration oriented radial to the longitudinal axis. The pistol grip may provide for increased visibility to the surgical site area during use of the hand piece **30**.

The ultrasound horn **40** may include a shaft **42** and a cutting blade **50** all driven by the ultrasound transducer **20**. The cutting blade **50** may be integral with or mechanically coupled to a shaft **42** or directly to the ultrasound transducer **30**. The shaft **42** and cutting blade **50** connections may be completed by threading, welding and/or other means readily recognizable by people of ordinary skill in the art. The ultrasound horn **40**, or portions of the ultrasound horn **40**, may be removable from the hand piece for cleaning, sterilization and/or replacement as would be understood by those skilled in the art upon review of this disclosure. The shaft **42** and cutting blade **50** may be fabricated from metals such as, but not limited to, alloys of titanium, aluminum and/or steel. The cutting blade **50** may be fabricated as a one-use disposable embodiment as an alternative to a sterilizable embodiment. To prevent premature material failure, the cutting blade **50** manufacture preferably does not include material bending, such as such as setting teeth angles by bending during cutting blade fabrication. Preferably the cutting blade **50** is manufactured by molding, casting or cutting operations as readily known in the art.

The cutting blade **50** has a preferred thickness of 1 mm. (millimeter). The range of thickness is typically from 0.1 to 10 mm. with the higher thickness blade often utilized for precision bone shaping applications, rather than precision cutting requiring a narrow kerf.

As shown in FIG. **3** (perspective view) and FIG. **4** (side view), the optional shaft **42** portion of the ultrasound horn **40** may have a longitudinal axis **41**. The shaft **42** is shown with a proximal section attached to the ultrasound transducer **30** and a distal section attached to the cutting blade **50** portion of the ultrasound horn **40**. A radial perimeter on the outer surface of the shaft **40** provides an entry/exit port for the conduit **43**. In a preferred embodiment, to prevent premature metal fatigue between the ultrasound horn **40** and the ultrasound transducer **20** and to provide efficient transmission of the ultrasound waves, the longitudinal axis **41** of the ultrasound horn is substantially co-linear with the longitudinal axis of the ultrasound transducer **20**.

The cutting blade **50** provides a support structure **54** to support a plurality of teeth **70**. The support structure **54** may be, for example, a rectangular or trapezoidal design. The support structure **54** at its proximal end is attached to the ultrasound horn **40** at its distal end. The support structure **54** would generally have a free distal end. It also may be curvilinear around its radial perimeter. The width of the support structure **54** is typically less than or equal to the maximum width of the cutting blade **50** to avoid severely limiting the depth of a cut. Preferably, the support structure **54** is narrower than the maximum width of the cutting blade **50**. The radial edge along which the teeth **70** are attached is preferably substantially parallel with the longitudinal axis **41**. The teeth **70** may be mounted along a curvilinear radial edge with a maximum angle of less than 45 degrees.

The teeth **70** are typically arranged in pairs with each tooth cutting a portion of the cut, with at least one pair of adjacent teeth **70** defining the total width of the cut. The teeth **70** emerge from a radial surface of the ultrasound horn **40** at the interface with the support structure **54** having a proximal face **71** and a distal face **72** forming angles with the support structure identified as proximal face angle A**2** and distal face angle A**3** respectively.

The proximal face **71** and distal face **72** meet to form a cutting edge **73** along a vertex **76** having a vertex angle A**1**. Vertex angle A**1** is preferably 60 degrees, but may vary from 10 to 170 degrees.

As shown in FIGS. **3** and **5**, the teeth **70** may be arranged along the longitudinal axis **41** with a tooth width Y and a tooth gap Z between adjacent teeth **70** resulting in a tooth spacing X. The length of Z may vary from 0 to 10 mm. with lengths less than 0.1 mm. preferred. The intersection of the tooth with the support structure **54** is preferable slightly rounded to reduce the potential for stress cracking at the intersection. The cutting edge **70** produces a kerf **77** defined by the width of the cutting edge **70** at its widest point. Kerf **77** having a width K is preferably 1 mm. with a range between 0.1 and 10 mm.

With reference to FIGS. **3** and **6**, FIG. **6** shows a cross section revealing portions of a pair of teeth. As shown, although each tooth **70** has an exterior face **74** and an interior face **75** originating from the support structure **54**, the relative position alternates with each tooth from the right side to the left side. The exterior face **74** intersects with support structure **54** forming a lower outer side angle C**1**. The interior face **75** intersects with the support structure **54** forming a lower inner side angle C**2**. Preferably the lower outer side angle is greater than the lower inner side angle.

The interior face **75** and exterior face **74** of a tooth intersect at a cutting edge **73**. The cutting edge **73** is preferably ⅓ of kerf **77** width K. The cutting edge **73** may be horizontal and parallel to the base of the tooth, or it may form an angle B with a horizontal projection of the cutting edge. The horizontal projection of cutting edge **73** may vary from 0 mm. to any dimension up to the width of the kerf **77**. At 0 mm. the cutting edge **73** is simply a point, and the interior face **75** and the exterior face **74** intersect at the point of the cutting edge **73**. The cutting edge **73** forms an upper outer side angle C**3** where it intersect with the exterior face **74** an upper inner side angle C**4** where it intersects with the interior face **75**.

Cutting of a bone surface occurs on the cutting edge **73** of the teeth **70**, the interior face **75** of the teeth **70** and to some extent on the exterior face **74** of the teeth. As a result, it is generally preferable to have a maximum width of the cutting blade **70** along the cutting edge **73**.

While the opposing exterior faces **74** of adjacent teeth generate the saw kerf **77** at their widest dimension. The opposing interior faces **75** of adjacent teeth form a gullet **80** that extends between each pair of teeth within the saw kerf **77**. The adjacent gullets **80** defined by the teeth **70** are interconnected among each other over the length of the cutting blade **70** to form a cavity along the cutting blade **70** that is substantially parallel to the longitudinal axis **41**. Although adjacent teeth are shown as opposing mirror images, this is not required. To change gullet **80** geometry, it is possible to, have an adjacent tooth somewhat smaller than another, or with a different described angle than the other.

The gullet **80** is an interconnected cavity running substantially parallel along the longitudinal axis **41** of the cutting blade **50** between the teeth **70**. It is the gullet that defines the space for bone chips to pass to be ejected from the saw kerf **77**. The gullet **80** also provides passages to distribute fluid along the cutting blade **50**. The gullet **80** may also define a ridge within the kerf **77** that allows temporary support for faces of the teeth **70**. This enhances stability which is particularly beneficial when starting precision cutting.

Chip ejection from the gullet **80** is of course defined by the geometry of the teeth, but also the spacing of the teeth and the gap between the teeth to produce a self-clearing design. Increasing the gap between the teeth provides for easier ejection of the bone chips.

In addition to the mechanical ejection to assist chip ejection due to the cutting blade vibrations from the longitudinal vibrations of the ultrasound horn **40**, the radial energy component of the ultrasound energy may be used to assist bone chip ejection. At each geometric intersection of the teeth **70** along the cutting blade **50**, the ultrasound waves may focus and/or concentrate ultrasonic energy. The emission of this energy may be used to move the bone chips from the gullet **80** or away from a tooth surface. For example, at the intersection of the various faces of the tooth **70** and intersection between the support structure **54** and the tooth **70** ultrasound waves may be concentrated and emitted. These waves may then assist the mechanical action to eject bone chips from within the vicinity of the cutting blade **50** and away from the kerf **77** itself.

Removing the bone chips from the vicinity of the cutting blade **50** prevents the cutting action of the cutting blade **50** from becoming an abrasive cutting action. This allows the bone tissue to remain at temperatures less than 75° C. which is a critical temperature for necrosis. Generally, with the use of this invention temperatures can be maintained at levels below 55° C.

FIG. **7** depicts a side view of an embodiment of the cutting blade **50** showing alternating teeth with a rounded tooth gap between the teeth **70** with interior and exterior faces forming isosceles triangle shapes.

FIG. **8** depicts a side view of an embodiment of the cutting blade **50** showing alternating teeth with forming right angles with a proximal face angle A**2** perpendicular to the longitudinal axis **41**. The teeth **50** are mounted along a curvilinear support structure while maintaining an overall configuration substantially parallel to the longitudinal axis.

FIG. **9** depicts a side view of an alternative embodiment of the cutting blade having curvilinear distal face **72** and proximal face **71** rather than a triangular face.

FIG. **10** depicts a side view of an alternative embodiment of the cutting blade having the cutting edge **73** positioned proximally to the remainder of the tooth **70** having the proximal face angle A**2** greater than 90 degrees.

As shown in FIGS. **7-10**, the although the cutting blade **50** may have a longitudinal axis **41** it is not required that all radial surfaces of the support structure **54** necessarily be parallel to the longitudinal axis, or that the cutting edges **53** be equidistance from the longitudinal axis **41**.

FIG. **11** depicts a cross sectional view of an alternative embodiment of the cutting blade **50** having a horizontal cutting edge **73** and the exterior face **74** on an imaginary plane being an extension of the imaginary plane of the support structure radial surface.

FIG. **12** depicts a cross sectional view of an alternative embodiment of the cutting blade **73** having the exterior face **74** on a different plane from the support structure radial surface.

FIG. **13** depicts a cross sectional view of an alternative embodiment of the cutting blade **73** forming a point at the intersection of the exterior face **74** and interior face **75** and also having the exterior face **74** with an interior angle.

FIG. **14** depicts a cross sectional view of an alternative embodiment of the cutting blade **73** having a curvilinear exterior face **74** and the support structure having a curvilinear radial perimeter.

FIG. **15** depicts a cross sectional view of an alternative embodiment of the cutting blade **73** having the exterior face **74** with an interior angle.

As shown within these example cross-sectional diagrams of FIGS. **11-15**, the kerf width is determined by the width of the cutting blade **50** at the cutting edge **73** or alternate teeth **70**.

Although specific embodiments of apparatuses and methods using the apparatus as an example, have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, combination, and/or sequence that is calculated to achieve the same purpose may be substituted for the specific embodiments shown. It is to be understood that the above description is intended to be illustrative and not restrictive. Combinations of the above embodiments and other embodiments as wells as combinations and sequences of the above methods and other methods of use will be apparent to individuals possessing skill in the art upon review of the present disclosure.

The scope of the claimed apparatus and methods should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

I claim:

1. An apparatus for use in surgery comprising:

an ultrasound generator driving an ultrasound transducer;

an ultrasound horn attached to an ultrasound transducer;

the ultrasound horn having a cutting blade disposed along a longitudinal axis;

the cutting blade having a support structure holding a plurality of teeth arranged on a surface, the surface defining a horizontal plane and extending parallel to the longitudinal axis;

the teeth extending upwardly from the surface and having a distal surface, a proximal surface, and a cutting edge extending substantially horizontally and partially across the width of the cutting blade in a direction substantially orthogonal to the longitudinal direction;

adjacent teeth cooperating to form a kerf wider than the support structure;

the teeth disposed along a radial edge of the horn;

a primary gullet formed between adjacent teeth interconnecting all teeth along the longitudinal axis; and

a plurality of secondary gullets defined by the distal and proximal surface of adjacent teeth wherein at least one of the surfaces defining each secondary gullet is substantially trapezoid shaped.

2. The apparatus according to claim **1** wherein the cutting blade has a width less than 1 millimeter.

3. The apparatus according to claim **1** wherein the ultrasound horn also has a conduit for transferring a fluid.

4. The apparatus according to claim **1** wherein the ultrasound horn is partially disposed within a shield.

5. The apparatus according to claim **1** wherein the ultrasound transducer receives a modulated signal.

6. The apparatus according to claim **1** characterized by the ultrasound transducer being capable of inducing the ultrasound horn to vibrate approximately in resonance at a frequency between 15 kHz and 3 mHz.

7. The apparatus according to claim **1** characterized by the ultrasound transducer being capable of inducing the ultrasound horn to vibrate approximately in resonance at a frequency of 30 kHz.

8. The apparatus according to claim **1** producing an electrical signal of a voltage sufficient to induce the ultrasound horn to vibrate approximately in resonance with the amplitude of the vibrations being between approximately 1 micron and 300 microns.

9. The apparatus according to claim **1** characterized by the generator being capable of producing an electrical signal of a voltage sufficient to induce the ultrasound horn to vibrate approximately in resonance with the amplitude of the vibrations being approximately 80 microns.

10. The apparatus of claim **1** wherein a housing has a grip portion having a substantially axial configuration along the longitudinal axis.

11. The apparatus of claim **1** wherein a housing has a grip portion in a pistol grip configuration radial to the longitudinal axis.

12. An apparatus for use in surgery comprising:

a drive mechanism communicating with a cutting blade;

the cutting blade having a high frequency vibration along a longitudinal axis;

the cutting blade also having a support structure holding a plurality of teeth arranged on a surface, the surface defining a horizontal plane and extending parallel to the longitudinal axis;

the teeth extending upwardly from the surface and having a distal surface, a proximal surface, and a cutting edge extending substantially horizontally and partially across the width of the cutting blade in a direction substantially orthogonal to the longitudinal direction;

adjacent teeth cooperating to form a kerf wider than the support structure; and

a primary gullet formed between adjacent teeth interconnecting all teeth along the longitudinal axis; and a plurality of secondary gullets defined by the distal and proximal surface of adjacent teeth wherein at least one of the surfaces defining each secondary gullet is substantially trapezoid shaped.

13. A self-clearing cutting blade for use in surgery comprising:

the cutting blade disposed along a longitudinal axis;

the cutting blade having a support structure holding a plurality of teeth arranged on a surface, the surface defining a horizontal plane and extending parallel to the longitudinal axis;

the teeth extending upwardly from the surface and having a distal surface, a proximal surface, and a cutting edge extending substantially horizontally and partially across the width of the cutting blade in a direction substantially orthogonal to the longitudinal direction;

adjacent teeth cooperating to form a kerf wider than the support structure; and

a primary gullet formed between adjacent teeth interconnecting all teeth along the longitudinal axis; and

a plurality of secondary gullets defined by the distal and proximal surface of adjacent teeth wherein at least one of the surfaces defining each secondary gullet is substantially trapezoid shaped.

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